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MELLON INSTITUTE

Quarterly Scientific Progress Report

Report No. 14

for the period

August 1, 1961 - October 31, 1961

STRESS CORROSION OF HIGH STRENGTH STEELS AND ALLOYS; ARTIFICIAL ENVIRONMENT

Research Project No. 389-2

Sponsored by
U. S. Army Ordnance, Frankford Arsenal
Mr. H. Rosenthal, Contract Monitor

Contract No. DA-36-034-ORD-3277RD

Approved H. L. Anthony

Dr. H. L. Anthony
Staff Adviser

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This Report Presented By The
Project Staff

C. J. Owen, Fellow
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TABLE OF CONTENTS

ABSTRACT

Stress corrosion test methods, apparatus, high strength alloy sample material for testing, sample preparation, sample testing, and present status of sample material are presented in brief.

Available heat treatment data for the PH15-7Mo, Vascojet 1000, D6Ac, and B120VCA alloys, heat treated to the approximate required strength levels of 200, 220, 240 Kpsi and maximum Y.S. (150, 170, and maximum for the titanium alloy) are given. Data for the remaining alloys, including 300M and Rocoloy 270 are in process.

Cumulative stress corrosion test data for the various bent beam and U-bend tests are presented. Included are bent beam data for 4137 Co and AM355 alloys, and U-bend data for AM355, PH15-7Mo, B120VCA, 4137 Co, and Ardeform 301. Indicated probability of proneness of these alloys to stress corrosion is discussed for each in accordance with the data presented.

I. INTRODUCTION

The project work described herein represents a portion of a grant made available by the Army to promote a general scientific advancement in the area of case materials for missiles. This specific project is concerned with the synthetic environment stress corrosion testing of specified high strength steels and alloys. The research objectives of the project were presented in Report No. 1.

Natural environmental tests on high strength steels and alloys are being conducted by Aerojet General Corporation, with actual production environments and rocket propellant environments being utilized. By prior mutual agreement, the same steel and alloy sheet material will be used for both projects and possible heat treatment variations will be circumvented by exchanging heat treated material whenever possible.

A number of drawings and schematic diagrams of apparatus and test methods pertinent to the project have been presented in prior reports. In addition, surveys of applicable industrial and military literature have also been presented previously (Reports 2 and 3).

This report presents further information on continuing U-bend and bent beam tests for the assigned alloys, and for Rocoloy 270, 4137 Co, and Ardeform 301 missile steels.

II. EXPERIMENTAL PROCEDURES

Test Methods

A discussion of the U-bend and bent beam test methods together with an outline of the synthetic stress corrosion test environments used in performing the research are given in the July, 1960, Monthly Scientific Report, Report No. 1.

All recently-exposed (and future) samples being subjected to stress corrosion testing are being weighed prior to exposure to the test solutions to provide, whenever possible, general corrosion information.

Apparatus

Schematic drawings of bent beam sample holders, the U-bend test and holders, a sample bending device for bent beam specimens, and a stress corrosion test tank were presented in Report Nos. 1 and 3.

Polyethylene containers are presently being used for the stress corrosion exposure of U-bend specimens to the various synthetic environments. Each container will adequately hold six U-bend specimens. The use of these containers will supplement the sample testing presently being conducted in epoxy-coated tanks.

Construction of shelving and an aeration system (Report No. 6) together with other pertinent items has facilitated (wherever feasible)

the transfer of samples under test from the glass containers to the epoxy-coated test tanks. The completed facility is illustrated in Report No. 7.

Alloy Sample Material

The alloys being used in the study on stress corrosion include:

1. Low Alloy: Ladish D6Ac.
2. Si-Modified 4300 Series: 300 M.
3. Hot-Worked Die Steel: Vascojet 1000.
4. Cold-Worked PH Steel: AM 355.
5. Heat-Treated PH Steel: PH15-7Mo.
6. Titanium Alloy: Bl20VCA.
7. Low Alloy-Cobalt Modified: 4137 Co.
8. Low Alloy-Cobal Modified: Rocoloy 270.
9. Stretch-Formed 17/7 Stainless Steel: Ardeform 301.

All of the sample material is being tested in sheet form and was procured as such.

Chemical analyses for the above listed alloys and for the comparative heats are given in their entirety in Table I in Report No. 13. Physical properties and heat treating surveys for the alloys were presented in Report No. 12.

Sample Preparation

Sheet material of the various alloys was sheared into slightly over-size U-bend, bent beam, and tensile specimens in both the primary (direction of lowest Y.S.) and secondary directions. The specimens were then wet-ground to width, length, and thickness (if necessary). Sample thickness was maintained between 30 and 50 mils, and as close to 50 mils as possible.

After heat treatment surveys were conducted (see Report No. 12) to determine the Y.S. variation with tempering temperature for each alloy (not necessary for AM 355), the specimens were heat treated to strength levels approximating 200, 220, 240 Kpsi and maximum Y.S. Heat treating of the B120VCA alloy consisted of aging in an inert atmosphere (see Report No. 12).

All the surfaces except the ends of the heat treated specimens were then polished with emery paper to remove oxide films, the final polish being administered with 240-grit emery. Care was taken to assure a uniformly square edge on the specimens. A tendency of the D6Ac, V-1000, and 300 M specimens to decarburize was circumvented by carefully wet-grinding the surfaces of the heat-treated samples an additional 5 mils per surface.

Sample Testing

The U-bend specimens were bent into a V-shape with a special bending apparatus, sprung into clips (see Report No. 12), and immersed in each of the five test solutions (one-molar NaCl, Na_2SO_4, $NaNO_3$, $NaPO_3$, and Na_2S).

The bent beam specimens were precision-cut to length and sprung into a holder with a bending device (see Report No. 12).

Status of Sample Material

The present status of the alloy sample material to date:

1. D6Ac - heat treatment incomplete.
2. 300M - heat treatment incomplete.
3. Vascojet 1000 - heat treatment incomplete.
4. AM355 - all U-bends and some bent beam samples under test.
5. PH15-7Mo - all U-bends but no bent beam samples under test.
6. B120VCA - heat treatment incomplete.
7. 4137 Co - under test.
8. Rocoloy 270 - undergoing final machining.
9. Ardeform 301 - under test.

III. EXPERIMENTAL

Sample preparation, heat treatment, and stress corrosion testing of all alloys noted in the previous section of this report are continuing.

1. Sample Preparation and Heat Treatment

During the period of this report, the PH15-7Mo, Vascojet 1000, D6Ac, and B120VCA U-bend and/or bent beam stress corrosion specimens were heat treated to the approximate strength levels required. These Y.S. level objectives were 200, 220, 240 and maximum Kpsi for the first three of the above and 150, 170, and 200 Kpsi for the B120VCA material. Heat treatment schedules were in accordance with the information presented in the heat treatment surveys (see Report No. 12) for these alloys.

While all heat treating (including 300M) is not as yet complete, the available tensile results for a number of these alloys are presented in Tables I (PH15-7Mo), II (Vascojet 1000), and III (D6Ac). The Y.S. level objectives of 200, 220, 240 and maximum Kpsi were not precisely obtained but the range of values is sufficient for test purposes. In addition, the Y.S. differential for the same tempering temperature in the two test directions (primary and secondary) was somewhat greater than was anticipated in some cases.

Photomicrographic work for the various as-received and heat treated alloys is incomplete and will be presented in the following report.

A considerable number of heat treated U-bend and bent beam samples are undergoing final surface preparation and it is expected that test data for same will also be presented in the next report.

2. Stress Corrosion Testing

The remainder of the as-received B120VCA U-bend samples and all of the heat-treated PH15-7Mo U-bend samples have been subjected to testing during the report period, with other batches soon to follow. With all the 4137 Co, AM355, and Ardeform 301 U-bends already under test, only the Vascojet 1000, D6Ac, 300M, and Rocoloy 270 samples remain.

Some difficulty was encountered in springing the higher strength transverse (primary direction; lowest Y.S.) heat-treated PH15-7 U-bends into their PVC clips. Fracture of these samples at the apex of the V (in the cross-section plastically deformed) occurred upon application of the degree of stress required to attach the clip. It may be surmised that, for example, the degree of elongation attainable in the longitudinal (rolling) direction was not sufficient to allow further deformation. This possibility is indicated by the data shown in Table X of Report No. 12, containing the heat treatment survey data for this alloy.

The problem was circumvented by placing the V-shaped sample on a 1/2-inch mandrel and then applying sufficient pressure to the sample ends to allow attachment of the clip.

Rearrangement of the tables of cumulative data has been undertaken to improve the clarity of comparison of results.

Bent beam specimens of 4137 Co and AM355 are still under test and U-bend testing of 4137 Co, AM355, PH15-7Mo, B120VCA, and Ardeform 301 is continuing. A more detailed discussion of the results to date for these alloys is provided in the following sections of this report.

Two additional cooperative projects are being undertaken on the effect of decarburization and alloying on the proneness to stress corrosion of low alloy missile steels. The information obtained will be presented at a later date.

a. Bent Beam Tests

The AM355 bent beam specimens (secondary direction) undergoing stress corrosion testing in the five test solutions (NaCl, Na_2SO_4, $NaPO_3$, $NaNO_3$ and Na_2S) have produced no failures to date for any test strength level (75% of 250, 261, and 302 Kpsi Y.S.), nor has there been any visual evidence (other than a slight discoloration in Na_2S) of any appreciable general corrosion. The cumulative data for these specimens is given in Table IV.

Bent beam specimens of 4137 Co, exposed to two natural environments (marine and semi-industrial) by U. S. Steel Applied Research personnel in a cooperative program, have undergone no change in status during the report period. The cumulative results to date are given in Table V.

Similar 4137 Co bent beam samples exposed to an industrial environment by this Project are reported in Table VI. There have been a few sample failures during the report period, none of which have included samples tempered at 1100°F for any Y.S. test level exposure. Comparison of the results to date from Tables V and VI (75% of Y.S. only) reveal the anomaly discussed in previous reports, i.e., the heavy industrial environment provides less susceptibility to stress corrosion than the mild industrial or marine environments. This variation from the expected is not immediately obvious, since sample preparation was identical, but is thought to be a function of sample preparation after heat treatment.

Tables V and VI also indicate that an 1100°F temper (75% of the maximum attainable Y.S. for this alloy) seems to provide immunity from stress corrosion, regardless of the test stress level (the tensile curve for this alloy shows little if any deviation from a straight line function up to the yield point). Stress corrosion susceptibility of this alloy may therefore be a function of the Y.S. attained by tempering.

Bent beam specimens for D6Ac, Vascojet 1000, 300M, PH15-7Mo, B120VCA, and the remaining direction of AM355 are expected to be all under test during the following report period.

b. U-Bend Tests

While all strength levels for the various assigned high strength steels and alloys and additional, selected alloys are not as yet under test, the cumulative U-bend test results to date are discussed in the following sections of this report.

1. AM355 - Only the lowest Y.S., primary direction, U-bend specimens are not under test for this alloy and, in view of the results to date, testing of added specimens seems unnecessary. The cumulative results for the low strength level (250 Kpsi Y.S. in secondary direction) samples shown in Table VII, the intermediate strength level (261 Kpsi Y.S. in secondary direction) samples, shown in Table VIII, and the high strength level (302 Kpsi Y.S. in secondary direction) samples, shown in Table IX, indicate a possible susceptibility to stress corrosion in NaCl only. If this were a structural weakness, it would be one in the direction of rolling (normal to the sample failure, since failure is predominantly associated with primary or transverse samples).

As Table X indicates, neither AM355 nor PH15-7Mo seem to be susceptible to carbon tetrachloride, pentane, or trichloroethane, although the higher-strength levels of PH-15 are not represented.

2. PH15-7Mo - The cumulative results for the low (201 Kpsi Y.S., primary direction), intermediate (208 Kpsi Y.S., primary direction), high (244 Kpsi Y.S., primary direction), and maximum strength (286 Kpsi Y.S., primary direction) levels, as presented in Tables XI through XIV, indicate no susceptibility of this alloy in any of the test environments. However, the higher strength specimens have not been exposed to testing for too long a period and any conclusion drawn would be preliminary at best.

3. B120VCA - The cumulative results for the as-received Primary Heat (Table XV) and Comparative Heat (Table XVI) show no susceptibility of this alloy to stress corrosion in any of the test solutions. The data, however, are largely inconclusive and the foregoing may be considered on a provisional basis, since greater bulk of the data are very short range. The higher strength samples will be in test for comparison in the next report.

4. 4137 Co - Table XVII data indicate that this low alloy missile steel is susceptible to stress corrosion failure in all test environments in widely varying degree. In general, the lower Y.S. (higher tempering temperature of 1100°F) samples were shown to be susceptible only in the phosphate and nitrate environments, the chloride, sulfate, and sulfide solutions having considerably less effect. The U-bend test data correlate on a general basis with the bent beam data

previously given for this alloy in that the percent Y.S. attained with regard to the Y.S. attainable seems to be one criteria for stress corrosion susceptibility.

The data in Table XVIII for this same steel show that dry air and laboratory environments have no apparent effect, whereas those samples exposed to a moist air environment are prone to failure at the higher Y.S. levels. Note that the 1100°F-tempered specimens are not affected even in the moist atmosphere.

5. Ardeform 301 - The cumulative data for Sample No. 1 of this material is presented in Table XIX and for Sample No. 2 in Table XX. There has been no change in status of these samples over the last report period. A possible proneness to stress corrosion in the chloride environment is indicated by the test data.

IV. FUTURE WORK

During the next report period the main research effort will be directed toward sample preparation, completion of sample heat treatment, and preparation for presentation of metallographic work.

Cumulative test results on bent beam and U-bend sample tests for all assigned and additional alloys will be presented.

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TABLE I

PHYSICAL PROPERTIES OF HEAT TREATED PH15-7Mo TEST SPECIMENS

PRIMARY HEAT

Precipitation Hardening Temperature °F	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	Fracture Strength Kpsi	Elongation % 1"	Elongation % 2"	Reduction in Area %
1125	Primary	208	214	226	13.3	10.0	17.2
	Secondary	224	229	259	6.0	5.7	13.6
1075	Primary	244	254	294	5.3	3.5	11.8
	Secondary	258	263	266	5.0	3.0	11.4
900	Primary	286	293	313	--	--	--
	Secondary	289	290	307	5.0	3.0	10.7

Note: All results are the average of 3 specimens.
Nominal tensile specimen thickness: .030".
Specimens were precipitation-hardened for 1 hr. at the above indicated temperatures.

TABLE II

PHYSICAL PROPERTIES OF HEAT TREATED VASCOJET 1000 TEST SPECIMENS

PRIMARY HEAT

Tempering Temperature	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	Fracture Strength Kpsi	Elongation % 1"	Elongation % 2"	Reduction in Area %
1100	Primary	196	231	269	11.5	7.8	22.7
	Secondary	207	245	271	--	5.5	14.4
975	Primary	256	323	359	12.0	7.5	16.5
	Secondary	260	327	369	10.0	7.0	17.0
850	Primary	237	305	343	--	5.0	19.3
	Secondary	246	309	375	15.0	10.0	21.4

Note: All results are the average of 3 specimens.
Nominal tensile specimen thickness: .052".
Specimens were preheated at 1450° F for 40 min., austenitized at 1900° F for 40 min., and triple tempered at the above indicated temperatures for 2 + 2 + 2 hrs.

TABLE III

PHYSICAL PROPERTIES OF HEAT TREATED D6Ac TEST SPECIMENS

PRIMARY HEAT

Tempering Temperature °F	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	Fracture Strength Kpsi	Elongation % 1"	Elongation % 2"	Reduction in Area %
550	Primary	239	264	288	8.3	5.1	18.4
	Secondary	248	271	342	8.0	5.0	30.5
840	Primary	206	218	264	10.0	6.0	25.2
	Secondary	223	229	290	12.0	7.3	30.6
1050	Primary	185	197	240	12.5	8.2	28.2
	Secondary	197	208	261	11.5	7.7	28.0

Note: All results are the average of 3 specimens.
Nominal tensile specimen thickness: .066".
Specimens were austenitized at 1550°F for 20 min. and double tempered at the above indicated temperatures for 2 + 1 hrs.

TABLE IV

CUMULATIVE AM355 STRESS CORROSION BENT BEAM TESTS

Test Solution	Direction* of Specimen	Applied Stress Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Secondary	180	6	none to 244 days	--	--
	Secondary	195	6	none to 228 days	--	--
	Secondary	226	6	none to 241 days	--	--
$NaNO_3$	Secondary	180	6	none to 244 days	--	--
	Secondary	195	6	none to 228 days	--	--
	Secondary	226	6	none to 241 days	--	--
Na_2S	Secondary	180	6	none to 244 days	--	--
	Secondary	195	6	none to 228 days	--	--
	Secondary	226	6	none to 241 days	--	--
Na_2SO_4	Secondary	180	6	none to 244 days	--	--
	Secondary	195	6	none to 228 days	--	--
	Secondary	226	6	none to 241 days	--	--
$NaPO_3$	Secondary	180	6	none to 244 days	--	--
	Secondary	195	6	none to 228 days	--	--
	Secondary	226	6	none to 241 days	--	--

Note: These specimens were cold-rolled to strength level.
The outer surface of the specimens is stressed to 75% of its Y.S.
(250 Kpsi, 261 Kpsi, and 302 Kpsi, resp.)

* Primary direction is direction of lowest Y.S. (transverse direction for this alloy).

TABLE V

CUMULATIVE 4137 Co STRESS CORROSION BENT BEAM TESTS*

Natural Environment	Applied Stress on Specimen** Kpsi	Direction of Specimen	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
Marine Exposure	190+	Primary	3	3	8	3 to 16
Kure Beach, N.C.	160++	Primary	5	5	13	6 to 18
	130+++	Primary	5	none to 370 days	--	--
Semi-Industrial	190+	Primary	5	5	19	2 to 30
Exposure	160++	Primary	5	5	35	18 to 45
Monroeville, Pa.	130+++	Primary	5	none to 370 days	--	--

* Cooperative testing program with U. S. Steel Applied Research Lab., Monroeville, Pa.
** All specimens stressed to 75% of Y.S.

Note: These specimens were austenitized at 1700°F for 30 min and tempered at 550, 750 and 1100°F for 2 + 1 hrs producing Y.S. of 255, 213, and 174 Kpsi, respectively.
The primary direction is direction of lowest Y.S.

\+ 550°F Temper ++ 750°F Temper +++ 1100°F Temper

TABLE VI

CUMULATIVE 4137 Co STRESS CORROSION BENT BEAM TESTS

Severe Industrial Exposure (Pittsburgh, Pennsylvania)

% of Y.S. for Test	Applied Stress on Specimen, Kpsi	Direction of Specimen	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
50	130+	Primary	6	4 to 243 days	--	--
	115 ++	Primary	5	none to 243 days	--	--
	95+++	Primary	6	none to 243 days	--	--
75	195+	Primary	6	6	47.2	30 to 65
	175++	Primary	6	3 to 243 days	--	--
	140+++	Primary	6	none to 243 days	--	--
90	230+	Primary	6	6	33.6	21 to 43
	200++	Primary	5	5	143.2	88 to 203
	170+++	Primary	6	none to 243 days	--	--

Note: These specimens were austenitized at 1700°F for 30 min and tempered at 550, 750 and 1100°F for 2 + 1 hrs producing Y.S. of 258, 232 and 191 Kpsi, respectively.
The primary direction is direction of lowest Y.S.

\+ 550°F Temper ++ 750°F Temper +++ 1100°F Temper

TABLE VII

CUMULATIVE AM355 STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Secondary	250	261	6	none to 42 days	--	--
$NaNO_3$	Secondary	250	261	6	none to 42 days	--	--
Na_2S	Secondary	250	261	6	none to 42 days	--	--
Na_2SO_4	Secondary	250	261	6	none to 42 days	--	--
$NaPO_3$	Secondary	250	261	6	none to 42 days	--	--

Note: These specimens were cold-rolled to strength.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is direction of lowest Y.S.(transverse direction of this alloy).
Specimen thickness - .038 inches.

TABLE VIII

CUMULATIVE AM355 STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	235	286	6	6	6.3	0.5 to 14.5
	Secondary	261	271	6	none to 41 days	--	--
$NaNO_3$	Primary	235	286	6	none to 41 days	--	--
	Secondary	261	271	6	none to 41 days	--	--
Na_2S	Primary	235	286	6	none to 41 days	--	--
	Secondary	261	271	6	none to 41 days	--	--
Na_2SO_4	Primary	235	286	6	none to 41 days	--	--
	Secondary	261	271	6	none to 41 days	--	--
$NaPO_3$	Primary	235	286	6	none to 41 days	--	--
	Secondary	261	271	6	none to 41 days	--	--

Note: These specimens were cold-rolled to strength level.
The outer surface of the test specimen is stressed beyond its Y.S.
Primary direction is the direction of lowest Y.S. (transverse direction for this alloy).
Specimen thickness - .0365 inches.

TABLE IX

CUMULATIVE AM355 STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	274	307	6	6	3.25	0.5 to 8
	Secondary	302	311	6	1 to 41 days	--	--
$NaNO_3$	Primary	274	307	6	none to 188 days	--	--
	Secondary	302	311	6	none to 41 days	--	--
Na_2S	Primary	274	307	6	none to 188 days	--	--
	Secondary	302	311	6	none to 41 days	--	--
Na_2SO_4	Primary	274	307	6	none to 188 days	--	--
	Secondary	302	311	6	none to 41 days	--	--
$NaPO_3$	Primary	274	307	6	none to 188 days	--	--
	Secondary	302	311	6	none to 41 days	--	--

Note: These specimens were cold-rolled to strength level.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is direction of lowest Y.S. (transverse direction for this alloy).
Specimen thickness - .033 inches.

TABLE X

CUMULATIVE PH15-7Mo AND AM355 STRESS CORROSION U-BEND TESTS

Test Solution	Type of Steel	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
Carbon tetrachloride CCl_4 (chlorinated non hydrocarbon)	PH15-7Mo	Primary	201	238	6	1 to 144 days	--	--
	PH15-7Mo	Secondary	218	221	6	none to 144 days	--	--
	AM355	Primary	274	307	6	none to 144 days	--	--
	AM355	Primary	235	286	6	none to 144 days	--	--
Pentane C_5H_{12} (non chlorinated hydrocarbon)	PH15-7Mo	Primary	201	238	6	none to 144 days	--	--
	PH15-7Mo	Secondary	218	221	6	none to 144 days	--	--
	AM355	Primary	274	307	6	none to 144 days	--	--
	AM355	Primary	235	286	6	none to 144 days	--	--
Trichloroethane C_2H_2Cl (chlorinated hydrocarbon)	PH15-7Mo	Primary	201	238	5	none to 144 days	--	--
	PH15-7Mo	Secondary	218	221	6	none to 144 days	--	--
	AM355	Primary	274	307	6	none to 144 days	--	--
	AM355	Primary	235	286	6	none to 144 days	--	--

Note: These specimens were cold-rolled to strength level.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is the direction of lowest Y.S.(transverse direction for this alloy).

TABLE XI

CUMULATIVE PH15-7Mo STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	201	238	6	none to 216 days	--	--
	Secondary	218	221	6	none to 216 days	--	--
$NaNO_3$	Primary	201	238	5	none to 216 days	--	--
	Secondary	218	221	6	none to 216 days	--	--
Na_2S	Primary	201	238	6	none to 216 days	--	--
	Secondary	218	221	6	none to 216 days	--	--
Na_2SO_4	Primary	201	238	5	none to 216 days	--	--
	Secondary	218	221	6	none to 216 days	--	--
$NaPO_3$	Primary	201	238	5	none to 216 days	--	--
	Secondary	218	221	6	none to 216 days	--	--

Note: These specimens are in the cold-rolled condition.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is direction of lowest Y.S.(transverse direction for this alloy).

TABLE XII

CUMULATIVE PH15-7Mo STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	208	214	6	none to 18 days	--	--
	Secondary	224	229	6	none to 18 days	--	--
$NaNO_3$	Primary	208	214	6	none to 18 days	--	--
	Secondary	224	229	6	none to 18 days	--	--
Na_2S	Primary	208	214	6	none to 18 days	--	--
	Secondary	224	229	6	none to 18 days	--	--
Na_2SO_4	Primary	208	214	6	none to 18 days	--	--
	Secondary	224	229	6	none to 18 days	--	--
$NaPO_3$	Primary	208	214	6	none to 18 days	--	--
	Secondary	224	229	6	none to 18 days	--	--

Note: These specimens were tempered at 1125°F for 1 hr.
The outer surface of the specimens is stressed beyond its Y.S.
Primary direction is the direction of lowest Y.S. (transverse direction for this alloy).

TABLE XIII

CUMULATIVE PH15-7Mo STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	244	254	6	none to 18 days	--	--
	Secondary	258	263	6	none to 18 days	--	--
$NaNO_3$	Primary	244	254	6	none to 18 days	--	--
	Secondary	258	263	6	none to 18 days	--	--
Na_2S	Primary	244	254	6	none to 18 days	--	--
	Secondary	258	263	6	none to 18 days	--	--
Na_2SO_4	Primary	244	254	6	none to 18 days	--	--
	Secondary	258	263	6	none to 18 days	--	--
$NaPO_3$	Primary	244	254	6	none to 18 days	--	--
	Secondary	258	263	6	none to 18 days	--	--

Note: These specimens were tempered at 1075°F for 1 hr.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is direction of lowest Y.S. (transverse direction for this alloy).

TABLE XIV

CUMULATIVE PH15-7Mo STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	286	293	6	none to 18 days	--	--
	Secondary	289	290	6	none to 18 days	--	--
$NaNO_3$	Primary	286	293	6	none to 18 days	--	--
	Secondary	289	290	6	none to 18 days	--	--
Na_2S	Primary	286	293	6	none to 18 days	--	--
	Secondary	289	290	6	none to 18 days	--	--
Na_2SO_4	Primary	286	293	6	none to 18 days	--	--
	Secondary	289	290	6	none to 18 days	--	--
$NaPO_3$	Primary	286	293	6	none to 18 days	--	--
	Secondary	289	290	6	none to 18 days	--	--

Note: These specimens were tempered at 900°F for 1 hr.
The outer surface of the specimen is stressed beyond its Y.S.
Primary direction is direction of lowest Y.S. (transverse direction for this alloy).

TABLE XV

CUMULATIVE B120VCA STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	139	140	4	none to 7 days	--	--
	Secondary	143	145	4	none to 299 days	--	--
$NaNO_3$	Primary	139	140	4	none to 7 days	--	--
	Secondary	143	145	4	none to 299 days	--	--
Na_2S	Primary	139	140	4	none to 7 days	--	--
	Secondary	143	145	4	none to 7 days	--	--
Na_2SO_4	Primary	139	140	4	none to 7 days	--	--
	Secondary	143	145	4	none to 7 days	--	--
$NaPO_3$	Primary	139	140	4	none to 7 days	--	--
	Secondary	143	145	4	none to 299 days	--	--

Note: These specimens are in the "as received" condition.
The outer surface of the specimen is stressed beyond its Y.S.
The primary direction is direction of lowest Y.S.

TABLE XVI

CUMULATIVE B120VCA(HT1)* STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	141	143	4	none to 7 days	--	--
	Secondary	144	148	4	none to 7 days	--	--
$NaNO_3$	Primary	141	143	4	none to 7 days	--	--
	Secondary	144	148	4	none to 7 days	--	--
Na_2S	Primary	141	143	4	none to 7 days	--	--
	Secondary	144	148	4	none to 7 days	--	--
Na_2SO_4	Primary	141	143	4	none to 7 days	--	--
	Secondary	144	148	4	none to 7 days	--	--
$NaPO_3$	Primary	141	143	4	none to 7 days	--	--
	Secondary	144	148	4	none to 7 days	--	--

*HT1 refers to comparative heat number 1.

Note: These specimens were taken in the "as received" condition.
The outer surface of the specimen is stressed beyond its Y.S.
The primary direction is direction of lowest Y.S.

TABLE XVII

CUMULATIVE 4137 Co STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Primary	258	285	6	6	4.3	0.5 to 11.5
	Primary	232	260	6	6	126.0	38 to 224
	Primary	191	198	6	3 to 467 days	--	--
$NaNO_3$	Primary	258	285	6	6	1.2	0.5 to 1.5
	Primary	232	260	6	6	33.8	29.5 to 39.5
	Primary	191	198	6	6	122.6	26 to 292
Na_2S	Primary	258	285	5	2 to 273 days	--	--
	Primary	232	260	6	1 to 273 days	--	--
	Primary	191	198	6	none to 273 days	--	--
Na_2SO_4	Primary	258	285	6	6	0.9	10 min to 2.5 days
	Primary	232	260	5	none to 407 days	--	--
	Primary	191	198	6	3 to 407 days	--	--
$NaPO_3$	Primary	258	285	6	6	4.5 min	3 to 6 min
	Primary	232	260	6	6	0.3 days*	34 min to 5 days
	Primary	191	198	6	6	1.5 days**	0.5 to 27 days

* One specimen lasting 5 days not averaged.

** One specimen lasting 27 days not averaged.

Note: These specimens were austenitized at 1700°F for 30 min and tempered at 550, 750 and 1100°F, respectively for 2 + 1 hrs.

The outer surface of the specimen is stressed beyond its Y.S.

The primary direction is direction of lowest Y.S.

TABLE XVIII

CUMULATIVE 4137 Co STRESS CORROSION U-BEND TESTS

Test Solution	Direction of Specimen	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
Dry Air (dessicator)	Primary	258	285	3	none to 274 days	--	--
	Primary	232	260	3	none to 274 days	--	--
	Primary	191	198	3	none to 274 days	--	--
Humid Air (satur. with water vapor)	Primary	258	285	4	4	6.4	4 to 11.5
	Primary	232	260	4	4	54.5	3 to 143
	Primary	191	198	4	none to 266 days	--	--
Laboratory (exposed directly to lab. environ.)	Primary	258	285	4	none to 266 days	--	--
	Primary	232	260	4	none to 266 days	--	--
	Primary	191	198	4	none to 266 days	--	--

Note: These specimens were austenitized at 1700°F for 30 min and tempered at 550, 750 and 1100°F, respectively for 2 + 1 hrs.
The outer surface of the specimen is stressed beyond its Y.S.
The primary direction is direction of lowest Y.S.

TABLE XIX

CUMULATIVE ARDEFORM 301 STRESS CORROSION U-BEND TESTS

(Sample 1)

Test Solution	Direction of Specimen	Test Surface in Tension	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Long.	Outside (convex)	183	229	4	4	1.25	0.5 to 2.0
	Long.	Inside (concave)	183	229	4	2 to 188 days	--	--
	Trans.	Outside	--	--	6	none to 188 days	--	--
$NaNO_3$	Long.	Outside	183	229	4	none to 188 days	--	--
	Long.	Inside	183	229	4	none to 188 days	--	--
	Trans.	Outside	--	--	6	none to 188 days	--	--
Na_2S	Long.	Outside	183	229	4	none to 188 days	--	--
	Long.	Inside	183	229	4	none to 188 days	--	--
	Trans.	Outside	--	--	6	none to 188 days	--	--
Na_2SO_4	Long.	Outside	183	229	4	none to 188 days	--	--
	Long.	Inside	183	229	4	none to 188 days	--	--
	Trans.	Outside	--	--	6	none to 188 days	--	--
$NaPO_3$	Long.	Outside	183	229	4	none to 186 days	--	--
	Long.	Inside	183	229	4	none to 186 days	--	--
	Trans.	Outside	--	--	6	none to 186 days	--	--

Note: These specimens are in the "as received" condition.
The outer surface of the specimen is stressed beyond its Y.S.

TABLE XX

CUMULATIVE ARDEFORM 301 STRESS CORROSION U-BEND TESTS

(Sample 2)

Test Solution	Direction of Specimen	Test Surface in Tension	Y.S. (.2% Offset) Kpsi	Tensile Strength Kpsi	No. of Specimens	Failures to Date	Average Time to Failure, days	Failure Time Range, days
NaCl	Long.	Outside (convex)	209	235	6	none to 158 days	--	--
	Long.	Inside (concave)	209	235	4	1 to 158 days	--	--
	Trans.	Outside	--	--	5	none to 158 days	--	--
$NaNO_3$	Long.	Outside	209	235	5	none to 158 days	--	--
	Long.	Inside	209	235	4	none to 158 days	--	--
	Trans.	Outside	--	--	5	none to 158 days	--	--
Na_2S	Long.	Outside	209	235	4	none to 158 days	--	--
	Long.	Outside	209	235	-	none to 158 days	--	--
	Trans.	Outside	--	--	5	none to 158 days	--	--
Na_2SO_4	Long.	Outside	209	235	4	none to 158 days	--	--
	Long.	Inside	209	235	3	none to 158 days	--	--
	Trans.	Outside	--	--	5	none to 158 days	--	--
$NaPO_3$	Long.	Outside	209	235	4	none to 158 days	--	--
	Long.	Inside	209	235	4	none to 158 days	--	--
	Trans.	Outside	--	--	5	none to 158 days	--	--

Note: These specimens are in the "as received" condition.
The outer surface of the specimen is stressed beyond the Y.S.

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